GARRETT RYLAND, Ph.D. (Johns Hopkins, '98), has been made professor of chemistry at Richmond College, Richmond, Virginia.

MR. A. V. HILL, Humphrey Owen Jones lecturer in physical chemistry at the University of Cambridge, has been elected a fellow of King's College.

MR. F. P. WHITE, St. John's College, has been elected to an Isaac Newton studentship at the University of Cambridge.

PROFESSOR SIEGFRIED GARTEN, of Giessen, has been called to the chair of physiology at Leipzig as successor to Professor E. Hering.

DISCUSSION AND CORRESPONDENCE

THE CURRENT "DEFINITION" OF ENERGY

TO THE EDITOR OF SCIENCE: In a book review by Professor Millikan[1] the reviewer incidentally mentions the existing confusion in the use of the word "energy." In my judgment, Professor Millikan's remark is fully justified; for it is not only the writers of text-books, but scientific writers of the first rank who find themselves more or less entangled with the current definition of energy and the terminology to which the definition leads because the terminology is inconsistent with a logical use of the facts. Recent and present writers are not wholly to blame for this state of affairs for they have inherited a "definition" and a terminology from the pioneers in the science of thermodynamics that conflict with facts whose full significance was discovered only after the terms were introduced and their use established. Under such circumstances confusion is inevitable until the terminology is revised to fit the facts.

Many of our text-books on physics "define" energy as the "capacity of doing work" (Maxwell), as the "ability to do work," or, even as the "power of doing work." This last is particularly reprehensible, because "power," as used in physics, is the rate of doing work. As a matter of fact, even if work were a form of energy, none of these definitions would be an adequate "definition" of energy any more than a quart measure would be a definition of "space." Because heat is a form of energy it does not follow that "energy is heat," or, because our standard of mass is a piece of platinum that "matter is platinum." But the above definitions of energy are worse even than the above logical absurdities would indicate, for work, as may easily be seen, is not even a form of energy, like heat, but is in reality merely a phenomenon that accompanies its transfer or transformation. The reason why our unit of work is also our unit of energy is that all of our measurements of work are *energy-changes* involving transfers which may be *measured* by the work done *on* or *by* a body or system. The actual doing of work is always found to depend upon the existence of *energy differences;* and these *differences* are just as essential to the doing of work and the transfer of energy as the presence of energy itself. This fact, which is ignored in the above definitions, is expressed in a variety of ways by the second law of thermodynamics. "The capacity of doing work," if the words are to mean anything definite should be taken as referring to the "availability of energy"; and the *availibility* of a thing is not the *thing* available. In explaining work and energy, Professor Millikan states:[2]

> . . . it is obvious that they are not synonymous terms, for a body may possess energy and yet never apply it to the production of work. Work is done only when energy is *expended.*

If he had here used the word "transferred" instead of "expended" his statement would confirm what I have been endeavoring to present.

There is no more necessity for a "definition" of energy than there is for a definition of "matter." Both are known only by their characteristic phenomena; and these characteristics must serve to identify them and to differentiate them from each other. With the "units" of each, however, the case is quite different. They may be defined in terms of

[1] SCIENCE, October 2, 1914, p. 486.

[2] "Mechanics, Molecular Physics and Heat," p. 42.

any *constant*, suitable, measurable, characteristic, phenomena. We do not have to "define" space because we have units of volume, or extension because we make use of meters, yards and feet. Next to an ignorance of facts, the principal source of confusion in the case of energy arises from using *one* characteristic attribute, and that not a universal one, as a "definition" of energy. Through supposing the indefinable to *be* defined, even the most careful writers are led into inconsistencies and mis-statements. The result, to the alert and critical student, is "confusion worse confounded." It does not follow that because our unit of work furnishes a very convenient and definite unit of energy that it is possible to "define" energy, or that work is a kind of energy. There is only one fundamental and universal characteristic of energy which we can be sure holds true for all of its various forms and that is its conservation. Energy is conserved; and this, if merely regarded as a postulate, necessitates our recognizing that when one form of it disappears another form takes its place. Equivalents of both can not exist at the same time. Hence, if work is a kind, or form, of energy it must possess and exhibit this characteristic, that while it exists in the form of work some other form must cease to exist, and *vice versa*. It can not be too strongly insisted upon that the property, or attribute, of conservation necessarily excludes all processes not included under transference and transformation. Again, although energy changes may be measured in terms of work the principle of conservation applies only to the energy; and it becomes possible to prove this principle only through the existence of some *one universal* form of energy into which all other kinds may be transformed. For it is evident that if there is no universal form there must be for each form, or kind, some special means by which it may be identified as energy and its equivalent value measured; otherwise the "principle of conservation" is a mere delusion, or purely imaginary. But so far as is now known all forms of energy without exception are susceptible to transformation into heat, either directly or indirectly through work, and their energy values determined in terms of heat. Hence for the present, at least, heat may be regarded as the universal form of energy.

In order to establish, definitely, the relation between heat and energy let us consider for a moment Joule's classical experiments for the determination of the mechanical equivalent of heat. The potential energy of the elevated weights *disappeared* during their descent and produced a quantity of heat which was measured. Now, by the principle of conservation, potential energy could be imparted to the weights only by the *disappearance somewhere* of an equivalent, either of heat, or of some potential form of energy. In either case, the elevated weights represented energy that has been accounted for without counting work *as energy;* hence the work done in elevating them can not have been energy. Nor is it in the case of the descending weights; for the potential energy of the descending weights disappears as potential energy and reappears as heat. *Work is then,* it can be seen, *a kind of process by means of which energy is transferred and transformed.*

Doubtless many will find it difficult to understand how the unit of work can be a correct and convenient unit of energy and yet not *be* energy. A parallel case is found in the measurement of temperature. The indications of the thermometric substance are due to heat yet are not heat; they must be interpreted as *ratios,* and merely show the relation of the temperature measured to some temperature assumed as a standard. Likewise a standard energy state is assumed and the *change* in the energy of the system may be measured by the work done *on* or *by* the system, an *inverse* corresponding change taking place in some other body or system. From the fact that the ratio of the work unit to the heat unit (energy) is known, the energy *change* is readily obtained by applying the ratio.

Since in teaching, concise, definite statements are desirable whenever possible, the current, defective and misleading "definitions" might be replaced by short statements like the following:

All physical phenomena are *effects* attributed to a universal activity called energy.

Since energy is conserved, or constant in amount, all of our experimental observations of it are limited to the various effects due to its transfer and transformations.

The doing of work indicates the transfer of energy (Maxwell).

All spontaneous natural processes may be made to do work (Nernst).

Transformations of energy take place accompanied by, or during, transfer.

Since writers of text-books and other writers who necessarily depend more upon authority than upon their own investigations and interpretations can doubtless quote the necessary "good authority" for their principal statements, when such statements are questioned, they will pay but little attention to adverse criticism so long as they have the necessary authority for their statements. This being only natural and reasonable, the foregoing view regarding the use and misuse of the words "work" and "energy" shall also be supported by quoting the necessary "high authority," Professor Clerk-Maxwell. All of the following quotations will be taken from two of his well-known and justly prized books, "Theory of Heat," tenth edition, which will be referred to as T. of H., and his "Matter and Motion," which will be referred to as M. and M. In addition to being a scientific investigator and mathematician of the first rank Professor Maxwell possessed a remarkable ability as a scientific writer and expositor.

The use of the term energy, in a scientific sense, to express the quantity of work a body can do, was introduced by Dr. Young (T. of H.), p. 91.

Dr. Young wrote at a time when the conservation of energy was yet unthought of. Hence Professor Maxwell "inherited" the definition—did not originate it. The inconsistencies in the following excerpts may safely be attributed to the growth of the subject and the failure of the later parts to agree with the older parts. A considerable part of the growth of the subject was due to the labors of Professor Maxwell himself.

For the energy of a body may be defined as the capacity it has of doing work, and is measured by the quantity of work it can do (T. of H., p. 90).

Energy is the capacity of doing work (M. and M., p. 101).

Perhaps those writers who "define" energy are not so much to blame, after all! They have, at least, "good authority." There could be no exception taken to the first statement if it confined itself to the following: "The energy of a body may often be measured by its capacity of doing work," *i. e.*, to transfer its energy; but there is no warrant for the last sweeping generalization that "energy is the capacity of doing work." It is indeed a striking example of a very common human trait—a tendency to repeat current familiar phrases without critical examination. Everybody does it more or less. All that the facts which he presented warranted him in claiming was that the capacity of doing work *is due to energy*, or, that *one important characteristic* of energy is its capacity of doing work, *i. e.*, of bringing about its own transfer.

Here then we have two sets of quantities, one relating to work, the other to heat. . . .

Of these quantities work and heat are simply two forms of energy (T. of H., p. 194).

It should be noted here that work is spoken of as a "form of energy."

The potential energy of a material system is the capacity it has of doing work depending on other circumstances than the motion of the system (M. and M., p. 120).

The preceding excerpts are sufficient to show the influence of Dr. Young's definition of energy. Some quite different statements as to the relation of work and energy will now be given—evidently the result of Professor Maxwell's own study of the subject, but whose full significance he did not then realize, or live to complete.

Work, therefore, is a transference of energy from one system to another; the system which gives out energy is said to do work on the system which receives it, and the amount of energy given out by the first system is always exactly equal to that received by the second (M. and M., p. 104).

Now it is evident as soon as the attention is called to it that work can not, at the same time, be both energy and the transference of energy. If two statements are inconsistent, one, at least, must be abandoned. Let us see which.

A similar inconsistency, or contradiction, is found in two recent, excellent, text-books, both by the same author, who quotes freely from Maxwell. In one book we find that "*energy is the capacity for doing work,*" while in the other book it is stated that "work may now be defined as the act of *transferring energy* from one body or system to another." If we combine these two statements in one we find that energy is the capacity for transferring energy!

The conflict evidently arises from retaining the old definition of Dr. Young which was introduced before the principle of conservation was recognized. It should be abandoned as no longer applicable. (See discussion of Joule's experiment given above, and the conclusion derived from it.)

In order to show that the last excerpt from Maxwell is not a mere slip of the pen but a conclusion based on evidence two additional excerpts will be given.

> The process by which stress produces change of motion is called work, and, as we have already shown, work may be considered as the transference of energy from one body or system to another (M. and M., p. 164).

> The transactions of the material universe appear to be conducted, as it were, on a system of credit. Each transaction consists of the transfer of so much credit or energy from one body to another. This act of transfer or payment is called work. The energy so transferred does not retain any character by which it can be identified when it passes from one form to another (M. and M., p. 166).

We have, then, a conflict of authority from the *same source* and we must, perforce, decide from the evidence and not on the authority, and that is decidedly in favor of the later and consistent view that work is a transference of energy and not a "form of energy." The authors of text-books have just as good authority, if they care to use it, for defining work as a process of transference of energy as they have for defining energy as "the capacity of doing work"; and by so doing can place themselves more nearly in touch with recent developments as to what constitutes the relation between work and energy.

We have had one "definition" of energy; the following statement, by way of contrast, might also be used as another.

> Hence, as we have said, we are acquainted with matter only as that which may have energy communicated to it from other matter, and which may, in its turn, communicate energy to other matter.

> Energy, on the other hand, we know only as that which in all natural phenomena is continually passing from one portion of matter to another (M. and M., p. 165).

This latter, and later, conception of energy seems, to my mind, a long step in advance over the conception of energy as the "capacity of doing work." In addition, it is in full accord with the later developments of our knowledge of energy and with the general principle of conservation.

If we *accept* the conservation of energy as an established *principle,* then we must accept the legitimate deductions from it or abandon it as a principle. It is plain that neither the view that energy is a capacity of doing work, nor the view that makes work a "form of energy" is consistent with considering work a *transference* of energy; and also that while the last view is consistent with the principle of conservation the other two are not. The consistent view, and to that extent at least, the true view is, so far as my knowledge goes, the personal contribution of Professor Maxwell. No earlier, or contemporary writer, so far as I know, and they are not numerous, makes such definite and specific generalized statements. His treatment of energy in "Matter and Motion" is a distinct advance over his treatment of it in his "Theory of Heat." No doubt that if he had lived a few years longer he would have renewed his study of energy and cleared up his apparent inconsistencies. His later years were devoted

mainly to his "Electromagnetic Theory of Light," "one of the most splendid monuments ever raised by the genius of a single individual." All of the early investigators in the theory of energy received a peculiar bias from the fact that the theory of energy was developed from the theory of work—the production of "useful work" being one of the most important problems in the life of nations as of men. Hence the statement that "energy is the capacity of doing work" was evidently received and accepted by scientific men before and during Maxwell's time as expressing an advanced scientific generalization; and even now, when not too critically examined, might pass as equivalent to the statement: Energy is the universal natural agency by means of which work is done. But while the former statement is logically weak and leads to ambiguities and contradictions the latter statement is perfectly definite, consistent with Maxwell's showing that work is a transference of energy and with that broad general principle, the conservation of energy.

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A PECULIAR BREED OF GOATS

TO THE EDITOR OF SCIENCE: There is a peculiar breed of goats raised in central and eastern Tennessee. When suddenly frightened the hind legs become stiff and the animal jumps along until it recovers and trots off normally or if greatly frightened the front legs become stiff also and the goat falls to the ground in a rigid condition. They have received the name of "stiff-legged" or "sensitive" goats.

The farmers in Tennessee prefer them because they do not jump fences. They are snow white and look like ordinary goats.

We are starting experiments to determine whether this is a dominant or recessive characteristic in comparison with a normal goat.

When this peculiar affliction first appeared I can not say, but it seems to be possessed by all the goats in the section named.

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SCIENTIFIC BOOKS

The Natural History of Hawaii: Being an Account of the Hawaiian People, the Geology and Geography of the Islands, and the Native and Introduced Plants and Animals of the Group. By WILLIAM ALANSON BRYAN, Professor of Zoology and Geology in the College of Hawaii. Honolulu, Hawaii, The Hawaiian Gazette Co., Ltd. 1915. Distributors, H. S. Crocker & Co., 565 Market Street, San Francisco; G. E. Stechert & Co., 151 West 22d Street, New York. Price $5.50.

In 1907 and 1908 the American Association for the Advancement of Science thought seriously of going to Hawaii in the near future for a summer meeting. Prominent citizens of Hawaii joined the association in anticipation of this visit, and invitations from Hawaiian institutions were received in number. The then governor of the Islands, Mr. Frear, called on the Permanent Secretary in Washington, and Professor W. A. Bryan, of the College of Hawaii, attended the Chicago and Dartmouth meetings of the association in 1908, urging the mid-Pacific meeting. But difficulties of transportation arose, and the plan was finally abandoned at least until some future date. Professor Bryan's effort, however, was not without result, since during his visit he gained his charming wife, and has now brought out his great book on the natural history of Hawaii, thus bringing the islands to the continental members of the association to console them for the abandonment of the Hawaiian meeting.

Practically alone among the great scientific societies in this country, the American Society of Naturalists has preserved in its title the old idea of natural history. The old natural history is still talked about and written about, while the old natural philosophy, so-called, has gone out. But the old-fashioned natural history books, with their great charm and interest to a large class of readers, are seldom published nowadays.

This book of Professor Bryan's, however, is a real natural history. It covers in its six hundred pages the whole field. Section I.,